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To
NBER,
Innovation Research Boot Camp, Cambridge, MA

January 31, 2026

Dear NBER Summer Institute,

I am writing to apply for the 2026 NBER Innovation Research Boot Camp. I am currently a Postdoctoral Fellow at Northwestern University, where my research examines the structure and evolution of technological innovation using large-scale patent data and AI-based measurement tools. My work seeks to better understand how inventions emerge, recombine, and accumulate impact over time, and how these processes relate to broader economic growth and innovation policy.

My research uses multimodal machine learning methods to construct structured representations of patents at scale. Specifically, I consider to integrat text, figures, classification codes, and citation networks. This allows me to move beyond traditional citation-based measures and directly analyze the underlying technological content of inventions. Using embeddings and network analysis, I study how technological fields fragment, recombine, and evolve. Furthmore, I test hypotheses related to cumulative innovation, divide-and-conquer problem solving, and the increasing specialization of knowledge.

One ongoing project examines whether modern innovation is increasingly organized around complementary partial solutions rather than single, problem-spanning breakthroughs. Drawing on large-scale U.S. patent data, I construct dynamic semantic networks to track how clusters of related inventions grow and integrate over time. This work connects to classic questions in the economics of innovation concerning recombination, cumulative knowledge production, and the organization of inventive activity. It also has policy implications for how we evaluate technological progress, measure impact, and design innovation incentives.

A second line of work develops AI tools for identifying technological contradictions and problem–solution structures within patents. By formalizing these structures computationally, I aim to generate new measures of inventive search and knowledge diffusion. This contributes to the measurement infrastructure needed to study innovation at scale and to better understand how policy, institutional environments, and funding structures influence technological trajectories.

I am eager to attend the Boot Camp to deepen my grounding in the economic foundations of innovation research and to connect my computational approach with frontier theoretical and empirical work in the field. In particular, I would benefit from engaging with the literature on growth, innovation policy, and the organization of R&D, and from feedback on how best to align large-scale AI-based measurement with core economic questions.

Thank you for considering my application. I would be grateful for the opportunity to participate in this program and to engage with the NBER innovation research community.

Recommender: **Prof. Brian Uzzi**
Richard L. Thomas Professor, Kellogg School of Management, Northwestern University
Email: uzzi@kellogg.northwestern.edu
Yours sincerely,
Zhu Wang

ZHU (ELLEN) WANG

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RESEARCH INTERESTS

Multimodal representation learning and optimization for deep neural networks, with applications to scientific and technical decision-making system such as patent analysis and innovation management.

EDUCATION

University of Illinois Chicago, Chicago, IL 2025
Ph.D., Computer Science
Advisor: Sathya N. Ravi, Isabel Cruz (deceased)
Course list: Computer Algorithms I, Data and Web Semantics, Intro to Machine Learning, Data Mining & Text Mining, Advanced Data Mining, Data Science for Networks, Advanced Machine Learning Thesis: Semantic-driven Multimodal Learning: Gradient-based Methods and Applications

University of Pittsburgh, Pittsburgh, PA 2015
M.S., Information Science. Advisor: Paul Munro

Northeastern University, China 2012
B.Mgt., Information Management and System. Advisor: Zhuchao Yu

RESEARCH EXPERIENCE

Postdoctoral Fellow, Northwestern University 02/2025 - present
Supervisor: Prof. Brian Uzzi
Visualizing Innovation: Multimodal Analysis of Scientific Evolution

Research Assistant, AIOpt Lab, University of Illinois at Chicago 2022 - 2025
Multimodal representation learning and applications

Research Assistant, ADVIS Lab, University of Illinois at Chicago 2016 - 2021
Applying deep learning methods on ontology matching; Data management and analytics for public health

Research Assistant, PICSO Lab, University of Pittsburgh 2014 - 2016
Scholarly knowledge discovery and link predictions for junior scholars

Research & Data science Intern, CCCIS, Chicago, IL 05/2022 - 08/2022
Vehicle damage prediction via computer vision foundation models and knowledge graphs

PUBLICATIONS

Bold *indicates my name.* * *indicates the student(s) I mentor.*

MANUSCRIPTS UNDER REVIEW:

[u1] **Improving Training-free Open-vocabulary Segmentation using Diffused Cuts**
Zhu Wang, Harsh Mishra*, Sathya N. Ravi

[u2] **Utilizing 2D Attention-Based Models for Memory Efficient 3D Reconstruction**
Raj Mehta*, Jason Alan Sulskis, **Zhu Wang**, Sathya N. Ravi

[u3] **Inventive Problem Solving with LLMs: A Benchmark for TRIZ Reasoning**
Zhu Wang, Brian Uzzi

Peer-Reviewed Journal/Conference Papers:

[J1] **Targeted Unlearning Using Perturbed Sign Gradient Methods With Applications on Medical Images**
*Transactions on Machine Learning Research (***TMLR), 2025.**

George Nahass*, **Zhu Wang**, Homa Rashidisabet, Won Hwa Kim, Sasha Hubschman, Jeffrey C Peterson, Ghasem Yazdanpanah, Chad A Purnell, Pete Setabutr, Ann Q Tran, Darvin Yi, Sathya N. Ravi

[c2] **DesignCLIP: Multimodal Learning with CLIP for Design Patent Understanding**
*Proceedings of the 2025 Conference on Empirical Methods in Natural Language Processing (***Findings of EMNLP 2025).**
Zhu Wang, Homaira Huda Shomee*, Sathya N. Ravi, Sourav Medya

[c3] **From Heart to Words: Generating Empathetic Responses via Integrated Figurative Language and Semantic Context Signals**
*The 63rd Annual Meeting of the Association for Computational Linguistics (***Findings of ACL 2025).**
Gyeongeun Lee*, **Zhu Wang**, Sathya N. Ravi, Natalie Parde

[c4] **A Survey on Patent Analysis: From NLP to Multimodal AI**
*The 63rd Annual Meeting of the Association for Computational Linguistics (***ACL 2025).**
Homaira Huda Shomee*, **Zhu Wang**, Sathya N. Ravi, Sourav Medya

[c5] **Optimizing Neural Network Training and Quantization with Rooted Logistic Objectives**
*The 28th International Conference on Artificial Intelligence and Statistics (***AISTATS 2025).**
Zhu Wang, Praveen Raj Veluswami*, Harsh Mishra*, Sathya N. Ravi

[c6] **IMPACT: A Large-scale Integrated Multimodal Patent Analysis and Creation Dataset for Design Patents**
*Thirty-eighth Conference on Neural Information Processing Systems (***NeurIPS 2024).**
Homaira Huda Shomee*, **Zhu Wang**, Sathya N. Ravi, Sourav Medya

[c7] **Implicit Differentiable Outlier Detection Enable Robust Deep Multimodal Analysis**
*Thirty-seventh Conference on Neural Information Processing Systems (***NeurIPS 2023).**
Zhu Wang, Sourav Medya, Sathya N. Ravi
TL;DR: An end-to-end VLM framework incorporating explicit knowledge graphs and OOD-detection.

Peer-Reviewed Workshop Papers & System Reports:
[w8] **EmpatheticFIG at WASSA 2024 Empathy and Personality Shared Task: Predicting Empathy and Emotion in Conversations with Figurative Language**
*Workshop on Computational Approaches to Subjectivity, Sentiment, & Social Media Analysis at (***ACL 2024).**
Gyeongeun Lee*, **Zhu Wang**, Sathya N. Ravi, Natalie Parde

[w9] **Contextualized Structural Self-supervised Learning for Ontology Matching**
*The 18th International Workshop on Ontology Matching (***OM@ISWC 2023).**
Zhu Wang

[w10] **Analysis of the impact of covid-19 on education based on geotagged twitter**
*Workshop on Modeling and Understanding the Spread of COVID-19 (***SIGSPATIAL 2020).**
Zhu Wang, Isabel Cruz

[w11] **Predictive analytics using text classification for restaurant inspections**
*Workshop on Smart Cities and Urban Analytics (***SIGSPATIAL 2017).**
Zhu Wang, Booma Sowkarthiga Balasubramani, Isabel Cruz

[w12] **Research on scenarios management for testing decision-making behavior in decision simulation environment**
*International Conference on Systems and Informatics (***ICSAI 2012).**
Zhu Wang, Zhuchao Yu, Yang Jiang, Xueying Hong

[s13,14] **AgreementMakerDeep Results for OAEI 2021, 2022**
*The 16th/17th International Workshop on Ontology Matching (***OM@ISWC 2021, 2022).**
Zhu Wang, Isabel Cruz

TEACHING EXPERIENCE

Guest Lecturer, University of Illinois Chicago, 2019 – 2024

- Introduction to Data Science - Topics on data preprocessing and exploratory data analysis
- Introduction to Machine Learning - Topics on Decision Trees and Regression Models
- Data and Web Semantics - Topics on Ontology Engineering
- Deep Learning for Computer Vision - Topics on Vision-Language Models

Teaching Assistant, University of Illinois Chicago, 2016 – 2024
Course list: Program Design I, Program Design II, Introduction to Data Science, Introduction to Machine Learning, Database Systems, Data and Web Semantics

MENTORING EXPERIENCE

PhD Students:

- Gyeongeun Lee (UIC CS) - Empathetic detection and response generation
- Homaira Huda Shomee (UIC CS) - Multimodal patent analysis
- George Nahass (UIC Medical School) - Medical imaging
- Jihae Choi (Northwestern Management) - AI for business management

Master CS students (UIC): Praveen Raj Veluswami, Harsh Mishra, Raj Mehta
Undergraduate CS Students (UIC): Yiming Wang, Angela Xu, Jenny Vuong, Brian Wilk, Rasleen Dhaliwal

INVITED TALKS & POSTER

Rooted Logistic Loss for Efficient Multimodal Learning with Quantization and Pruning
Multimodal Artificial Intelligence Workshop 2024, TTIC, August 2024
Integrating Semantic Insights in Gradient Based Multimodal Learning
University of Chicago, December 2023
Accelerated Neural Network Training with Rooted Losses
2023 Conference on the Mathematical Theory of Deep Neural Networks, November 2023
Multimodal Representation Learning and Applications
NICO, Northwestern University, November 2023
Multimodal Representation Learning
University of Chicago, October 2023
Differentiable Outlier Detection Enable Robust Deep Multimodal Analysis
Midwest Machine Learning Symposium 2023, May 2023

ACADEMIC SERVICES

Conference Reviewer/Program Committee member: AISTATS 23 &24 &25, NeurIPS 23 &24 &25, ICLR 24 &25 &26, ICML 24 &25, ECCV 24, MICCAI 24 &25, AAAI 25, SDM 25, ICCV 25, WACV 26, CVPR 26
Guest Editor/Journal Reviewer: Special issue on Ontology Matching and Machine Learning of the Semantic Web Journal, Journal of Social Computing

AWARDS & HONORS

Graduate Student Council Travel Award, University of Illinois at Chicago	2018, 2023
Graduate SIS Scholarship, University of Pittsburgh	2015
National Undergraduate Scholarships, Northeastern University, China	2008-2012

Research Essay

Innovation Structure and the Measurement of Technological Progress

My research investigates how technological knowledge evolves, recombines, and accumulates impact over time. I focus on developing new empirical tools to measure the structure of innovation using large-scale patent data, with the goal of answering core questions in the economics of innovation: How is inventive activity organized? How does knowledge recombine across fields? And how do structural changes in innovation shape long-run growth and policy outcomes?

A central theme in my work is that modern innovation increasingly follows a divide-and-conquer structure. Rather than single inventions spanning entire problem domains, progress often emerges from complementary partial solutions developed in parallel and integrated later. This shift affects how we measure impact, productivity, and innovation policy, yet traditional metrics such as citations do not capture the evolving structure of technological content. To address this, I build large-scale measurement frameworks that integrate patent text, figures, classification codes, and citations into unified representations of technological knowledge. These representations allow me to construct dynamic networks that track how technological clusters emerge, fragment, recombine, and accumulate impact over time.

In ongoing work using U.S. patent data, I study how technological clusters evolve and recombine over time. Preliminary evidence suggests that many high-impact technologies arise not from isolated breakthroughs, but from dense recombination across previously separate domains. This pattern aligns with theories of cumulative innovation and increasing specialization, and speaks to debates about whether innovation is becoming more fragmented or team-dependent. A second line of research develops methods to identify problem–solution structures within patents, enabling measurement of technological constraints and trade-offs. These tools allow me to examine how inventors resolve contradictions and whether certain forms of constraint relaxation are associated with higher impact or faster diffusion, providing new empirical proxies for inventive search and the direction of technological change.

Looking forward, my research advances along three directions. First, I aim to model the divide-and-conquer dynamics observed in patent networks and link patterns of recombination to economic outcomes such as firm entry, productivity growth, and inequality. Second, I plan to examine how policy environments, such as funding structures and intellectual property regimes, which will shape the density and direction of knowledge recombination. Third, I seek to refine measures that distinguish incremental refinement from integrative breakthroughs, moving beyond patent counts and citations toward structural indicators of technological progress that better inform policy debates.

I am applying to the NBER Innovation Research Boot Camp because my work bridges new measurement approaches with foundational questions in innovation economics. While my training equips me to build large-scale empirical tools, I seek deeper engagement with theories of endogenous growth, inventive search, and R&D organization. The Boot Camp would help me more tightly connect my measurement frameworks to central economic debates and refine the theoretical grounding of my research. More broadly, I aim to contribute empirical foundations that clarify how the structure of technological change shapes productivity, inequality, and long-run growth.

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February 13, 2026

Dear NBER Innovation Boot Camp committee,

It is my pleasure to offer my strongest recommendation for **Dr. Zhu Wang** for a tenure-track Assistant Professor position. I worked closely with Dr. Wang as her postdoctoral supervisor at Northwestern University's Institute on Complex Systems (NICO) and the Kellogg School of Management, following her PhD in Computer Science at the University of Illinois at Chicago, and I can state without reservation that she is an exceptional researcher with rare technical depth, strong interdisciplinary instincts, and a sharp eye for important questions.

Dr. Wang's scholarship sits at the intersection of AI, knowledge discovery, and innovation science, with a distinctive focus on knowledge-driven multimodal systems that integrate text, images, and graph representations to study technological change at scale—work that is both methodologically rigorous and conceptually grounded, and that speaks directly to machine learning, computational social science, and innovation studies. She is also remarkably productive (14 publications, including six in 2025), with additional work in the pipeline (including two papers with me, one currently under review at ACL). At Northwestern she played a central role in developing TRIZBench, a large-scale patent-based benchmark motivated by the TRIZ framework, which highlights how innovation often proceeds through resolving technical contradictions (e.g., improving battery life increases weight) by identifying those contradictions and cataloging systematic strategies for resolving them; this project exemplifies her ability to translate substantive theory into scalable, impactful AI infrastructure.

Professor Brian Uzzi
<https://www.kellogg.northwestern.edu/faculty/uzzi/htm/index.htm >
Kellogg School of Management McCormick School of Engineering Department of Sociology Co-Director Northwestern Institute on Complex Systems